SECTION 10
MIX DESIGN METHODS

There is no universally accepted asphalt emulsion-aggregate mix design method for either dense or open-graded cold mixtures. However, nearly all of the dense-graded methods are modifications of the Hveern (ASTM D 1560 and 1561 or AASHTO T 246 and 247) or Marshall (ASTM D 1559 or AASHTO T 245) test methods.

The attempt in this chapter is to standardize two design methods for use with asphalt emulsion cold mixtures. One method is for the design of mixes having dense-graded aggregate and the second for mixes having open-graded aggregate. The method for open-graded mixes is based on a procedure developed by the Pennsylvania Department of Transportation. In trying to achieve somewhat standardized design procedures, consideration is given to currently used designs, availability of equipment and different emulsion and aggregate types. These procedures should be viewed as provisional as new procedures and equipment, such as those resulting from the Strategic Highway Research Program (SHRP), will be applied to future asphalt emulsion-aggregate mix design procedures.

10.1 Dense-Graded Aggregate Mix Design

This design method is for asphalt emulsion cold mixtures containing dense-graded mineral aggregates with a maximum size of 25 mm (1 in.) or less and either medium or slow setting types of emulsions. This design method is applicable to mixtures produced by either road or plant mixing at ambient temperatures and whether placed immediately or stockpiled for later placement.

10.1.1 Aggregates

Dense-graded aggregates meeting the requirements of **Table 7-2 Aggregates for Dense-Graded Emulsion Mixtures** are among those suitable for asphalt emulsion mixtures. For the gradations containing appreciable fines, aeration or drying prior to compaction may be required.

10.1.2 Asphalt Emulsions

Two types of asphalt emulsions are used for producing dense-graded emulsion cold mixtures — slow setting (SS) and medium setting (MS) types. Medium setting emulsions are normally used with aggregates that do not have excessive amounts of material passing the 75-µm (No. 200) sieve and/or if stockpiling of the mixture is desired. Conversely, slow setting emulsions normally are used with more dense aggregates [higher amounts of material passing 75-µm (No. 200) sieve] and stockpiling is not desired.

10.1.3 Determination of Trial Emulsion Content

There are several procedures available to determine a design starting point for the trial emulsion or residual asphalt content of a mixture. For this design procedure, two simple formulas are used within the procedure — one for base mixtures and another one for surface mixtures. The formulas are based on the percentage of aggregate passing the 4.75 mm (No. 4) sieve and in most cases will give a satisfactory starting point.

1. Determine the Residue Content of the Asphalt Emulsion to be used using ASTM D 244, “Residue and Oil Distillate by Distillation”.
2. Estimate an Initial Emulsion Content based on the Dry Weight of Aggregate using the appropriate formula for the mix being designed:

10.1.4 Base Mixtures

$$\% \text{ Emulsion} = \frac{(0.06 \times B) + (0.01 \times C) \times 100}{A}$$

10.1.5 Surface Mixtures

$$\% \text{ Emulsion} = \frac{(0.07 \times B) + (0.03 \times C) \times 100}{A}$$

where:

% Emulsion = Estimated initial percent asphalt emulsion by dry weight of aggregate

A = Percent residue of emulsion by distillation (Step 1)

B = Percent of dry aggregate passing 4.75 mm (No. 4) sieve

C = 100 - B = Dry aggregate retained on 4.75 mm (No. 4) sieve

10.1.6 Coating and Adhesion Testing

The preliminary evaluation of each asphalt emulsion selected for mixture design is accomplished through a coating test and an adhesion test. The trial emulsion content determined above is combined with the damp job aggregate, corrected to a dry weight. The coating is visually estimated as satisfactory or unsatisfactory for the intended use of the mix. Surface mixtures normally require a much greater degree of coating than do base mixtures.

Some asphalt emulsions may require pre-mixing water. If balling of the asphalt with fines is observed, coating at additional water contents should be evaluated. If the degree of coating is considered satisfactory, then the adhesion test is completed. If the coating is considered unacceptable, the emulsion used should be modified or another emulsion selected and the mix design started over.

10.1.6.1 Coating Testing Procedure

1. Determine the moisture content of a representative sample of the aggregate. Care must be taken to maintain the moisture in the field sample. If the aggregate is received dry or dried for blending, the estimated stockpile moisture must be added to the aggregate or individual combined aggregate samples 24 hours prior to performing any test.
2. Weight the equivalent of 500 grams of dry aggregate (500 grams + moisture) into a suitable mixing bowl.
3. If required, weigh in the premixing water and mix by hand for 10 seconds or until visually uniformly dispersed.
4. Weigh in the trial emulsion content to the moist aggregate at the anticipated use temperature and mix vigorously by hand for 60 seconds or until sufficient dispersion has occurred throughout the mixture.
5. Place the mixture on a flat surface and visually estimate the degree of coating. If desired, a portion of the fresh mix can be evaluated for water resistance by totally submersing the mix in water (about twice the volume of water to mix) and then pouring off the water, placing the mixture on a flat surface and visually estimating the degree of retained coating. If satisfactory, check the asphalt adhesion. If the adhesion is not acceptable, then the emulsion used should modified or another grade selected.

10.1.6.2 Adhesion Testing Procedure

1. Cure a 100 gram portion of the above produced mix (not submersed in water) in a shallow container for 24 hours in a forced draft oven at 60°C (140°F).
2. Put the oven-cured mix in a 600-ml beaker containing 400 ml of boiling distilled water.
3. Bring the water back to boiling and maintain boiling and stir the water at one revolution per second for three minutes.
4. Pour off the water and place the mix on a piece of white absorbent paper.
5. After the mix has dried, visually evaluate the amount (percent) of retained asphalt coating. If satisfactory, continue the mix design or if not acceptable, then the emulsion used should be modified or another grade selected.

10.1.7 Preparation of Test Specimens

Prepare three or more specimens each at a minimum of three different emulsion contents, with one below and one above the trial emulsion content. If the mixture in the coating test appears to be dry, start with the trial emulsion content and increase the content for each of the other two content levels. Conversely, if the mixture in the coating test appears rich, reduce the content for the other levels. A normal difference between the emulsion contents is one percent, or a residual asphalt content difference of 0.65% for an emulsion with a 65% residual content.

10.1.7.1 Mixing Procedure

1. Weigh into suitable mixing bowls the appropriate amount of wet job aggregate, corrected to a dry aggregate weight, to obtain a compacted specimen height of 63.5 ± 6 mm (2-5 ± 0.25 in.) for each individual batch. The amount normally required is about 1200 grams of dry aggregate. Care must be taken so that the aggregate for each batch is representative of the project aggregate. If necessary, the aggregate can be dried, separated into sizes, and then reblended into individual batch sizes. If this is done, water equivalent to the stockpile or desired moisture content must be added to each batch and the batch covered to prevent loss of moisture for about 24 hours prior to mixing with emulsion.
2. If pre-mix water is required, weigh onto the aggregate the predetermined amount as determined in the coating test and hand mix for 10 seconds or until the moisture is uniformly dispersed. This must be completed immediately prior to the addition and mixing of the emulsion.
3. Weigh the predetermined amount of emulsion onto the ambient damp aggregate and stir vigorously for 60 seconds or until sufficient emulsion dispersion has occurred in the mixture.

10.1.7.2 Compaction Procedure

1. Aeration or drying of a dense-graded mixture is often required prior to specimen compaction. Any time the total liquid volume (emulsion + water in aggregate) exceeds the voids mineral aggregate (VMA) plus any absorbed liquid volume, proper compaction cannot be achieved. This condition can be identified if the Marshall hammer bounces and/or liquid exudes from the specimen. When this condition exists, place the mixture in a shallow container and use a fan and occasional stirring to reduce the moisture content so that proper compaction can be achieved. Always use a new batch and not the one that could not be compacted satisfactorily.
2. Thoroughly clean the specimen mold assembly and the face of the compaction hammer. Place a paper disc in the bottom of the mold before the mixture is introduced. Transfer the entire batch into the mold and spade the mixture vigorously with a spatula 15 times around the perimeter and 10 times over the interior of the mold. With the spatula, smooth the surface of the mix into a slightly rounded shape.
3. Place the mold assembly on the compaction pedestal in the mold holder and apply 50 blows with the compaction hammer with a free fall of 457.2 mm (18.0 in.). Remove the base plate and collar and reverse the molded specimen and reassemble. Apply 50 blows of compaction to the face of the reversed specimen.
4. Remove the base plate, collar and paper discs, and place the mold containing the compacted specimen on a perforated shelf in a 60°C (140°F) forced draft oven for 48 hours. For some mixtures, it may be necessary to push the specimen down level with the bottom of the mold so that the oven shelf supports it during curing.

5. Remove the mold containing the compacted specimen from the oven and while still at 60°C (140° F), apply a static load of 178 kN (40,000 lbs.) by the double plunger method where a free-fitting plunger is placed at both the bottom and top of the specimen in the mold. Apply the load at a rate to give about 1.3 mm/min. (0-05 in./min.) of compression and maintain the full load for one minute and then release.
6. Allow the compacted specimen to cool in the mold for a minimum of one hour prior to extracting the specimen for testing.

10.1.8 Testing of Compacted Specimens

Approximate volumetrics and stability values can be determined from the compacted specimens if desired. The volumetrics often are not evaluated because they are normally calculated only as approximations because of the possibility of some moisture in the cured compacted specimens and the larger number of specimens required for more exact values. If more exact values are desired, the moisture must be accounted for in the compacted specimens and the theoretical maximum density must be determined using moisture free, loose mixture.

10.1.8.1 Volumetrics

1. The easiest and most often used method to determine bulk density is to divide the weight of the specimen in air by its measured and calculated volume. If for no other reason, the bulk density should be determined so that the compaction and/or composition of like specimens are validated.

$$D_b = \frac{W_a}{H \times A}$$

where:

D_b = Measured bulk density of a compacted mixture specimen

W_a = Compacted specimen weight in air

H = Height of compacted specimen

A = Cross sectional area of a compacted specimen (r2)

2. Other volumetrics, such as voids, voids filled and voids in mineral aggregate, etcetera can be determined by properly accounting for moisture and following the appropriate ASTM testing procedures, including D 70, D 1188, D 2041, D 2726 and D 3203.

10.1.8.2 Stability Testing

1. Marshall stability and flow are determined following the procedures of ASTM D 1559 beginning at paragraph 5 (Procedure), except that the compacted specimens shall be placed in an air bath for a minimum of two (2) hours at the test temperature of 25 ± 1°C (77 ± 1.8°F). A stability value of 2224 N (500 lbs.) or greater has been found to be satisfactory for most pavements with low to mod-

erate traffic volumes. Local experience may justify a different minimum stability value.

2. Hveem stability is determined following the “Resistance to Deformation” procedures of ASTM D 1560 (paragraphs 4 through 9), except that the compacted specimens shall be placed in an air bath for a minimum of two (2) hours at the test temperature of 25 ± 1 °C (77 ± 1.8°F). A stability value of 30 or greater has been found to be satisfactory for most pavements with low to moderate traffic volumes. Local experience may justify a different minimum stability value.

10.2 Open-Graded Aggregate Mix Design

This mix design method covers procedures for preparing trial mixtures of open-graded emulsion mixtures using aggregates having gradations as indicated in Table 6.3-6 of this manual. Job aggregate and a compatible asphalt emulsion are used to establish an optimum emulsion content based on an evaluation of asphalt runoff. Medium setting asphalt emulsions are used for open graded mixtures.

To summarize this method, mixtures are made with varying emulsion contents in one percent increments and subjected to a runoff method to determine the asphalt residue runoff. The asphalt emulsion content that gives an asphalt residue runoff of 10 grams is recommended as the optimum emulsion content.

10.2.1 Preparation of Mixtures

These procedures are used for the preparation of open-graded aggregate-asphalt emulsion mixtures for testing and determination of the optimum emulsion content.

1. Obtain a representative sample of job aggregate and dry to a constant weight in a forced draft oven at 60°C (140°F). After oven drying, cool the sample at ambient temperature for a minimum of two hours.
2. Preweigh a sufficient number of 2000-gram batch samples of the dried aggregate using the average stockpile gradation.
3. Using stainless steel bowls, mix the aggregate with 40 grams of water (2%) until all of the aggregate is damp. Cover the bowl with a clean cloth and leave covered for 15 minutes.
4. Add the appropriate amount of asphalt emulsion preheated to 60°C (140°F) to the dampened aggregate and prepare the mix by hand mixing for 2 minutes using a log-handled spoon. Observe and record the workability of the mix, such as stiff, satisfactory or sloppy, and the percent of coating. Emulsion contents in 1.0% increments by weight of dry aggregate are recommended. A beginning emulsion content of 4.0% is recommended for very coarse maximum size aggregates and 6.0% for the finest maximum size aggregates.

10.2.2 Testing Procedures

1. Immediately after preparation of the mixture, transfer the whole batch onto a 2.36 mm (No. 8) sieve that is placed above the tared standard pan. Prior to transferring the mix, lightly dampen the 2.36 mm (No. 8) sieve with water.

2. Allow the mix to drain into the standard pan at ambient temperature for 30 minutes.
3. Lift off the 2.36 mm (No. 8) sieve containing the drained mix and determine and record the mass of the standard pan containing the drained emulsion/runoff (W_1). Subtract the tared weight of the pan to determine the Asphalt Runoff in grams.
4. Remove the drained mix from the 2.36 mm (No. 8) sieve and spread the mix onto a paperlined tray. Surface dry the mix with a fan and evaluate the percent of asphalt coating.
5. Place the standard pan containing runoff in a forced draft oven at 110 ± 5°C (230 ± 9°F) and dry to a constant mass. Determine and record the final mass (W2). Subtract the tared weight of the pan to determine the Asphalt Residue Runoff in grams.

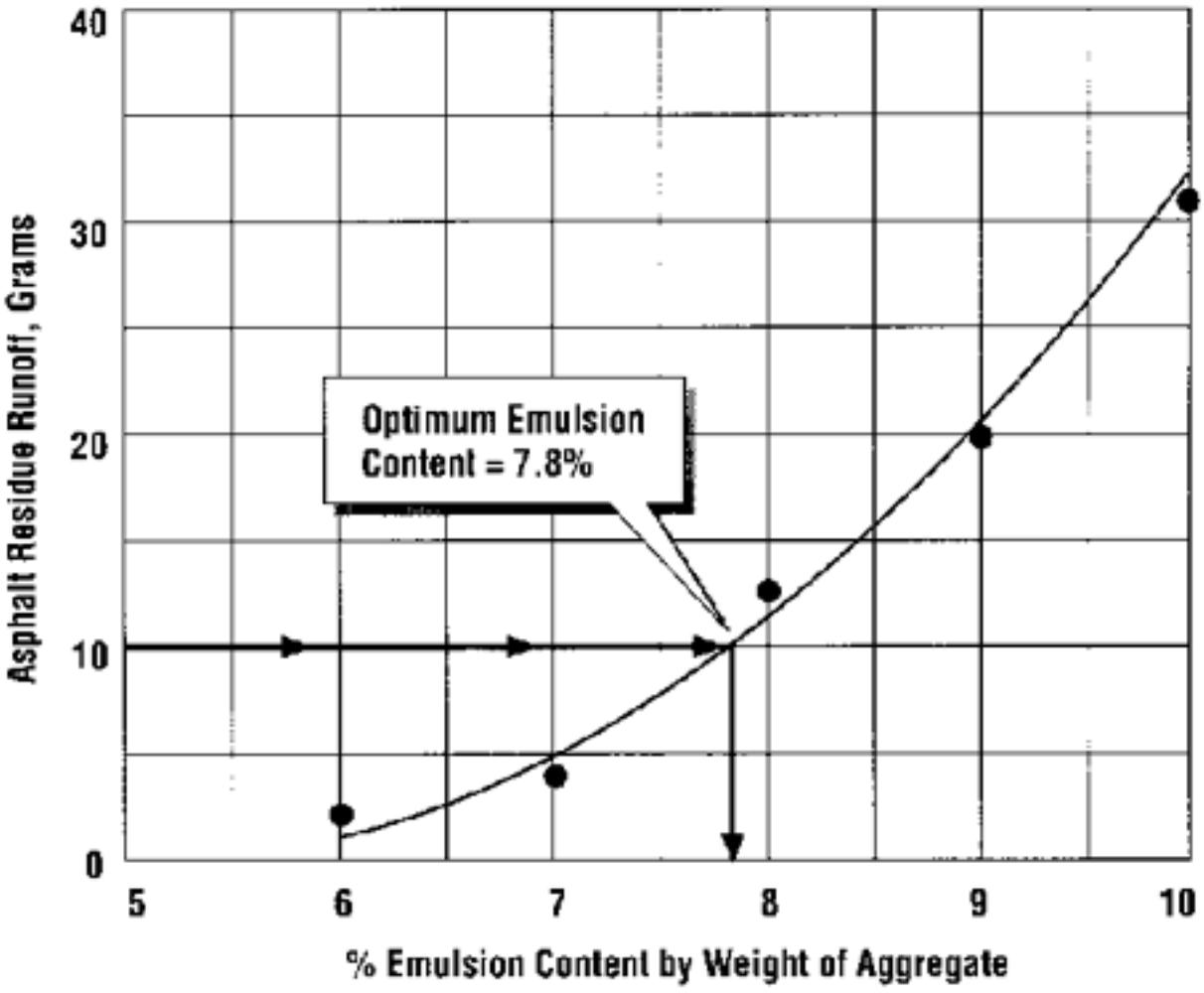

Figure 10-1 Selection of Optimum Emulsion Content Open-Graded Aggregate-Asphalt Emulsion Mixture

10.2.3 Optimum Emulsion Content Determination

1. Plot the % Emulsion Content by Weight of Aggregate versus the Asphalt Residue Runoff in grams on a graph and draw a smooth curve (**Figure 10-1 Selection of Optimum Emulsion Content Open-Graded Aggregate-Asphalt Emulsion Mixture**).
2. Draw a horizontal line at 10 grams of Asphalt Residue Runoff on the Y-axis to intersect with the curve. Read the corresponding % emulsion content on the X-axis to the nearest 0. 1 percent. This is the optimum emulsion content.

10.2.4 Final Results

Report these results:

1. Optimum Emulsion Content, percent
2. Mix Workability (stiff, satisfactory or sloppy)
3. Mix Coating, percent

At the optimum asphalt emulsion content, the mixture must have satisfactory workability. It is preferred that coating be as close as possible to 100%. Mixes shall be considered suitable, however, if they have a minimum of 85% coating if used as a surface course and 60% coating if used as a base course.